A Relativistic Symmetry in Nuclei

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The dynamics of neutrons and protons in nuclei have been successfully treated non-relativistically. Therefore it has come as a surprise that the fact that certain quantum states in heavy nuclei have almost the same energy (quasi-degeneracy), which has eluded understanding for about thirty years, can be explained by a relativistic symmetry. The states that are quasi-degenerate have different radial quantum numbers and different orbital angular momenta, features which made the reason for their quasi-degeneracy difficult to penetrate.

The Dirac equation, not the Schrödinger equation, must be used to describe the relativistic dynamics of nucleons moving in a mean field. In the Dirac equation two types of potentials are possible, one a relativistic scalar and one a relativistic vector. When the scalar potential is equal to the vector potential, but opposite in sign, there is a symmetry of the Dirac equation. This symmetry manifests itself by having certain quantum states degenerate in energy. The states that are degenerate have exactly the radial quantum numbers and orbital angular momenta of the quasi-degenerate states that have been observed.

The Dirac eigenfunctions have what are called "upper" and "lower" components. One of the predictions of this pseudospin symmetry is that the spatial amplitudes of the lower components for the two states in the degenerate doublets should be equal in magnitude. We have tested this condition by examining the lower amplitudes of the Dirac eigenfunctions determined in relativistic mean field calculations of nuclear spectra using realistic vector and scalar potentials [1]. In Fig. 1 we show an example of the amplitudes of the lower components of two states of a pseudospin doublet in an axially symmetric deformed nucleus. The amplitude of an axially symmetric deformed nucleus is a function of the distance along the symmetry axis, the z-coordinate, and the direction perpendicular to the symmetry axis, the ρ coordinate. In the upper row of Fig. 1 a contour plot of the amplitudes of the two states in the doublet are plotted with respect to the z and ρ in units of Fermis. In the lower row of Fig. 1 the difference of these two amplitudes is plotted versus the same coordinates. As seen in the Fig. 1 the amplitudes are almost identical. Pseudospin symmetry also imposes conditions on the upper amplitudes that involve differential relations between the amplitudes. A survey of other states in both deformed and spherical nuclei for pseudospin symmetry in both upper and lower components show that pseudospin symmetry conservation increases as the orbital angular momentum and binding energy decrease [1, 2].

Quantum chromodynamics, the fundamental theory of the strong interactions, predicts that the vector and scalar potentials in nuclei are almost equal in magnitude and opposite in sign, which is consistent with approximate pseudospin symmetry. This suggests that there may exist a more basic rationale for pseudospin symmetry in nuclei in the interactions among quarks. This connection is being investigated.

[1] J.N. Ginocchio, A. Leviatan, J. Meng, and Shan-Gui Zhou, "Test of Pseudospin Symmetry in Deformed Nuclei," *Phys. Rev. C* **69**, 034303 (2004).
[2] J.N. Ginocchio, "Pseudospin Symmetry and Relativistic Mean Field Eigenfunctions," *Phys. Rev. C* **66**, 064312 (2002).

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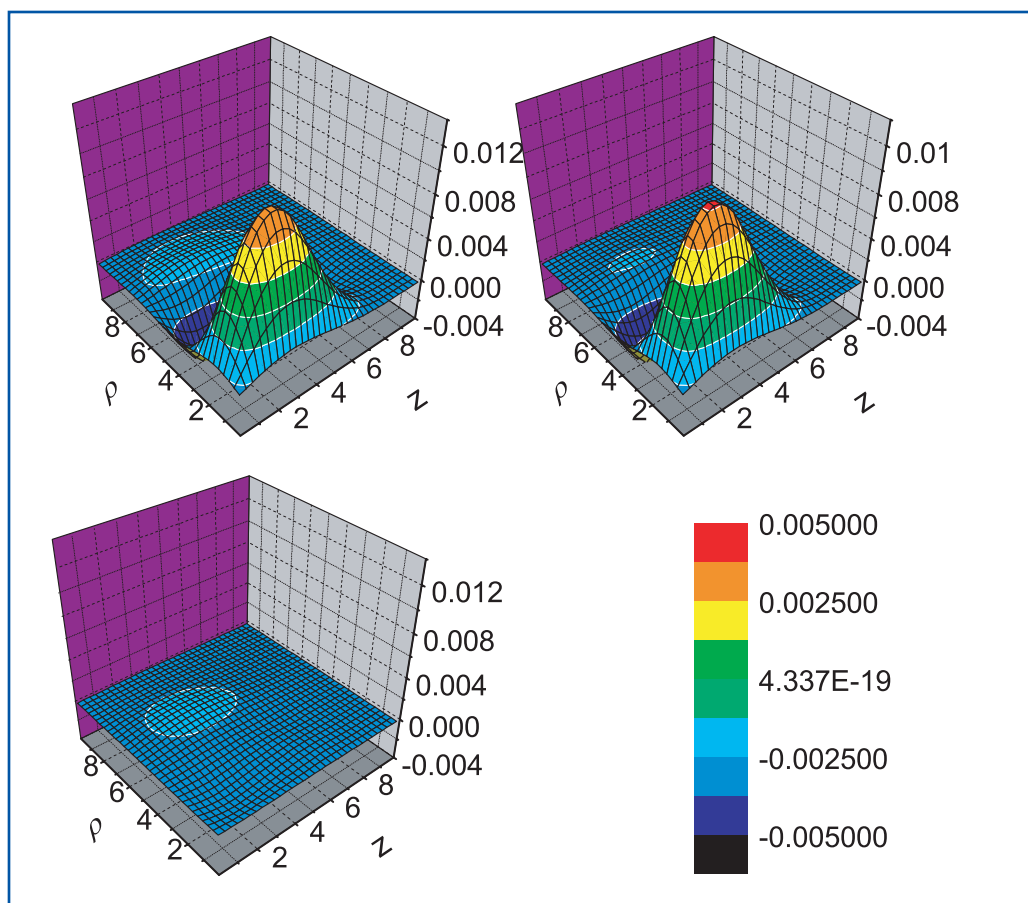
Figure 1—
An example of the amplitudes of the lower components of the two states of a pseudospin doublet in an axially deformed nucleus. In the upper row a contour plot of the amplitudes of the two states in the doublet are plotted versus the z and ρ coordinates in Fermis. In the lower row the difference of these two amplitudes are plotted versus the same coordinates.